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Water saturation and stiffness of chalk from Halfdan and Dan fields, Danish North Sea

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Introduction

The assessment of stiffness is essential to reservoir modeling, particularly in chalk, where compaction is an important recovery mechanism but also may lead to subsidence of the sea floor, as classically observed in the Ekofisk field. In this study, we assess the control of water saturation on stiffness of chalk in two wells from the Dan and Halfdan fields as expressed in Biot's coefficient α, a measure of cementation and correlated with stiffness in porous rocks.

Materials and Methods

The Dan field is a large structural dome with a thick hydrocarbon zone divided in two blocks by a large SW-NE striking fault, while the deeper Halfdan field, a flank development of the Dan field, is a flat structure with a thin hydrocarbon zone. The reservoir section of the chalk can be stratigraphically divided into three main units: Upper (D1) and Lower (D2) part of Ekofisk Formation (Danian age) and Tor Formation (M) (Maastrichtian age) and is characterized by high porosity (up to 45%) and low matrix permeability (up to 5mD). Whereas in the Dan field, permeability is probably enhanced by sub-vertical fractures, features as these are not observed in the Halfdan field.

Continuous well logs, wireline formation tester (RFT) data, and core data from two wells, representing each field, were used to calculate S_w by Archie's equation, where the porosity exponent was derived from porosity and permeability from cores (Olsen et al., 2008). Both wells, contain and an oil bearing interval, the Halfdan well also a gas bearing interval. In order to estimate Biot's coefficient in the absence of sonic shear logging data, P-wave modulus of a saturated rock, M_{sat}, was calculated from sonic and density logs. P-wave modulus of the frame M_{dry}, was then estimated by approximated Gassmann substitution (Mavko, 1998), where fluid modulus, M_{fluid}, was derived by mixing the modulus of water and hydrocarbon phases according to the Voigt average (Katika et al., 2017).

Results

Values of Biot's coefficient and S_w for the three reservoir units are cross plotted in Figure 1 (a, b and c). An obvious correlation between α and S_w, was found for both wells in the Upper Ekofisk Formation, D1, and Tor Formation, M. A similar trend was not found for the D2 interval. In the Ekofisk Formation intervals, S_w in the Dan field well is lower for a given α than in the Halfdan field

well. In the Tor Formation interval, including the transition and water zone, the Dan field well has higher Biot's coefficient for a given S_w than the Halfdan field well.

Discussion

The clear offset in Biot's coefficient in the water zone of the Halfdan and Dan field wells is probably caused by the difference in depth and consequent higher effective stress and temperature in the Halfdan field which have furthered pore-filling cementation. As water saturation decreases in the two wells, the difference in Biot's coefficient decreases as a reflection of the diminished pore filling cementation in the oil zone, probably caused by restricted diffusion from the water zone stylolites, which are a probable source of cement. In the Ekofisk Formation, the shift to higher water saturation for a given Biot's coefficient in the Halfdan field reflects a lower capillary pressure than in the Dan field. The unit D2 is known to have intervals rich in silica cement which causes local low Biot's coefficient. Nevertheless, data points from these intervals will display artificially high calculated α values due to the use of calcite mineralogy in Gassmann's and Biot's equations ($M_{calcite} >> M_{quartz}$).

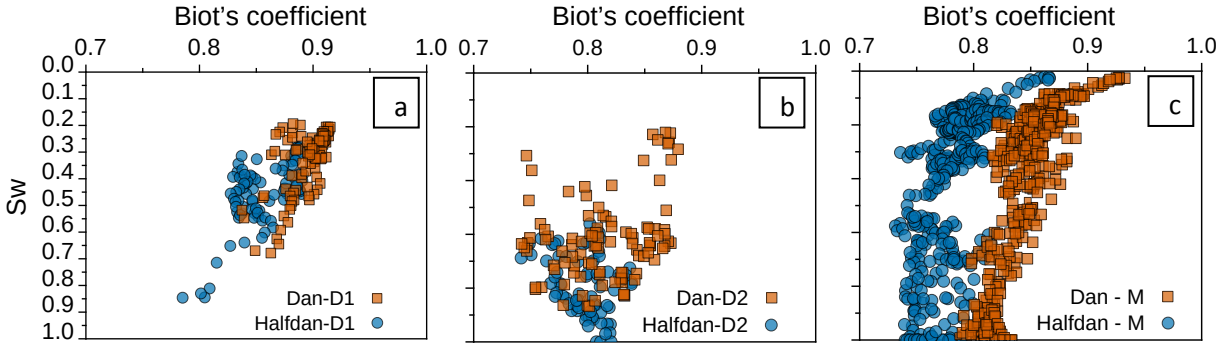

Figure 1 - Water saturation (vertical axes) versus Biot's coefficient for reservoir units D1 and D2 (Ekofisk Formation) and M (Tor Formation).

Conclusions

A correlation was found between Archie's water saturation and Biot's coefficient for chalk units in the Dan and Halfdan fields. This correlation highlights the link between pore stiffening cementation and diffusion from the water zone. A clear effect of capillary pressure on S_w was seen in the uppermost units. Difference in burial stress and temperature is reflected in difference in Biot's coefficient.

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